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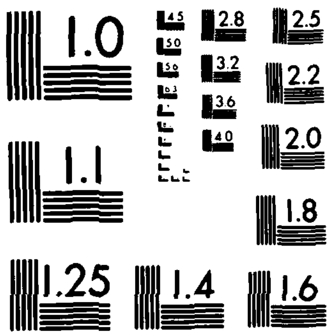

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REPORT SD-TR-84-51

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Defocusing Losses in a Log Periodic-Fed Reflector

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Log periodic designs are a well established wideband antenna technology, but one in which the phase center travels along the structure as the frequency varies. When a log periodic antenna is used as a feed for a reflector antenna, the phase center location cannot be maintained at the reflector focus over the frequency range and defocusing results. The purpose of this analysis is to quantify the defocusing loss for a log periodic-fed reflector. The analysis presented compares favorably with measured results.

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CONTENTS

FIGURES

I. INTRODUCTION

Reflector antennas for wideband operation require a feed design capable of the specified bandwidth. In addition to the required impedance bandwidth, ideally, the feed design should have pattern characteristics which are frequency independent and are sized for optimum illumination for the f/D of the selected reflector, and have a phase center which is constant with frequency that can be placed at the focus of the reflector. The log periodic feed fulfills the impedance and pattern requirements, but its phase center does not remain fixed with frequency changes. The analysis developed here will quantify the defocusing loss which occurs when a log periodic feeds a reflector and will be compared with measured results.

At the outset, the term "wide bandwidth" should be qualified. The variation in phase center location of the log periodic results in dispersion, i.e., low frequency components have longer insertion time delay than high frequency components. A consequence of this situation is delay distortion for very wideband signals; e.g., if a short pulse were transmitted, the pulse shape would be distorted by the dispersion, and an example is given in Ref. 1. The log periodic-fed reflector antenna, therefore, is appropriate for applications which require a wide tuning range with a narrow instantaneous bandwidth or for systems which operate at widely separated frequencies.

II. ANALYSIS

The analysis of the defocusing loss can be separated into a determination of the phase center location for the log periodic as a function of frequency and the loss in gain for a given phase center displacement from the reflector focus. These two elements are combined to quantify the defocusing loss as a function of frequency.

A. PHASE CENTER VARIATION

A log periodic antenna consists of an array of dipole elements whose lengths progressively change to cover the required operating range. The shortest element length corresponds to a half wavelength at the highest frequency and the longest element corresponds to a half wavelength at the lowest frequency. The elements are arranged as shown in Fig. 1. In operation, the antenna is fed at the apex and the energy travels along the structure until it

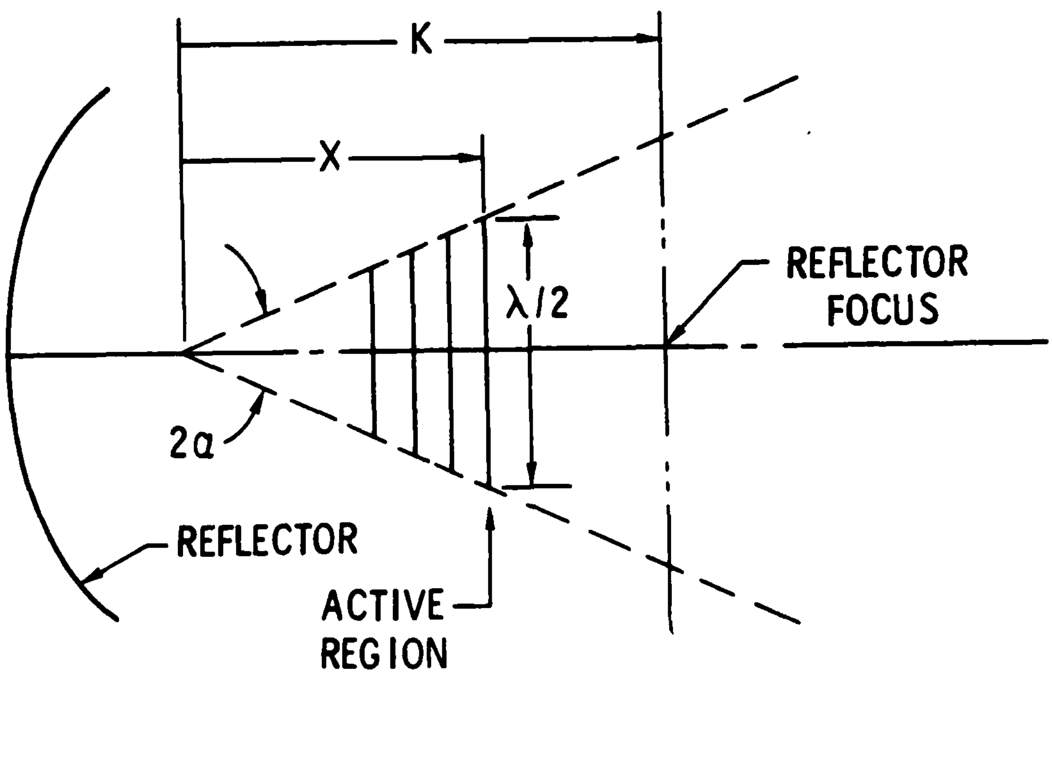

Fig. 1. Geometry of Log Periodic-Fed Reflector

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encounters an element which resonates at the operating frequency which corresponds to a half wavelength element length. The dipole elements which are excited at a particular frequency are referred to as the active region which, in turn, corresponds to the phase center location. Since a similar number of elements are excited over the bandwidth, the pattern characteristics of the log periodic are independent of frequency. These patterns for a typical log periodic are optimum in the sense of illumination efficiency for reflector antennas with f/D values of about 0.4, a common value.

The phase center location of the log periodic as a function of frequency can be easily calculated from the geometry given in Fig. 1. Define x as the distance measured from the projected apex of the log periodic. The focus of the reflector is assumed to be located a distance K from this projected apex as well. The phase center displacement relative to the focus is given by

$$\Delta\lambda = X - K = \frac{\lambda}{4\tan\alpha} - K \tag{1}$$

where Δ is the phase center displacement in wavelengths. The defocusing loss for a reflector as will be discussed later depends on the phase center displacement in wavelengths.

Log periodic antennas with very wide bandwidth performance are commercially available from several vendors. Commercial designs with bandwidths which exceed 10:1 are typical. A design measured from 1 to 21 GHz is described in Ref. 2. The practical limitations for the operating frequency for these designs are the physical size of the longest element at the lowest frequency and the fabrication difficulties at the apex feed section at the highest frequency where small dimensions are required.

B. REFLECTOR DEFOCUSING LOSS

A general analysis of the defocusing loss for a reflector antenna has been presented in Ref. 3 and will be used here. The defocusing loss depends on the illumination pattern of the feed and the f/D of the reflector. The analysis developed in Ref. 3 considers defocusing loss and spillover loss components for feed patterns which follow the $\cos^n\theta$ family. The defocusing loss values given in Fig. 2 are taken from Ref. 3 and apply to reflectors having an f/D of 0.4. The defocusing loss is not strongly dependent on the

f/D and is symmetric with respect to both positive and negative displacements from the reflector focus.

The beamwidth of a typical log periodic antenna is 65° and 110° in the E and H planes, respectively. The average beamwidth in the principal planes corresponds to the 90° beamwidth of the cos θ illumination which will be used in the subsequent computations. The defocusing loss for this illumination is shown in Fig. 3 and was derived from the values given in Fig. 2. It should be noted that the cos θ illumination for a reflector with f/D of 0.4 provides

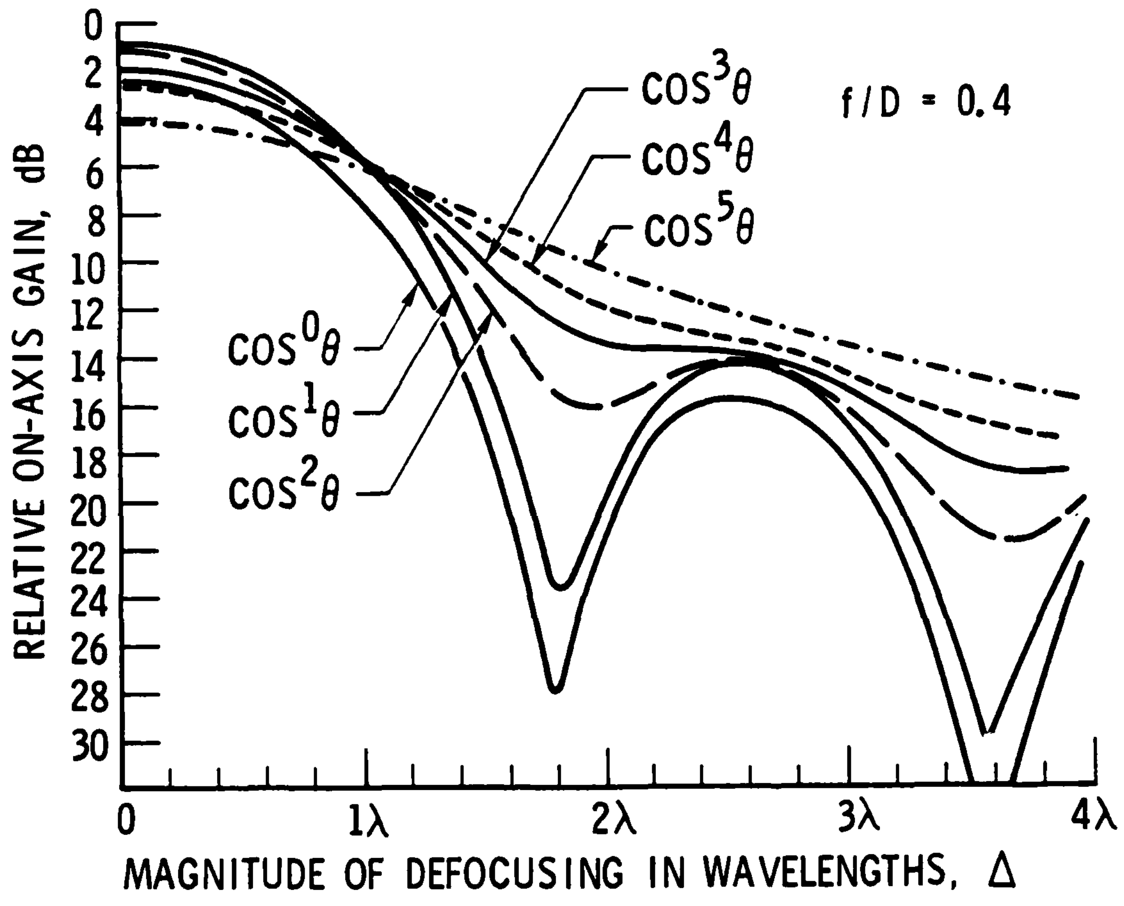

Fig. 2. Defocusing and Spillover Losses (after Ref. 3)

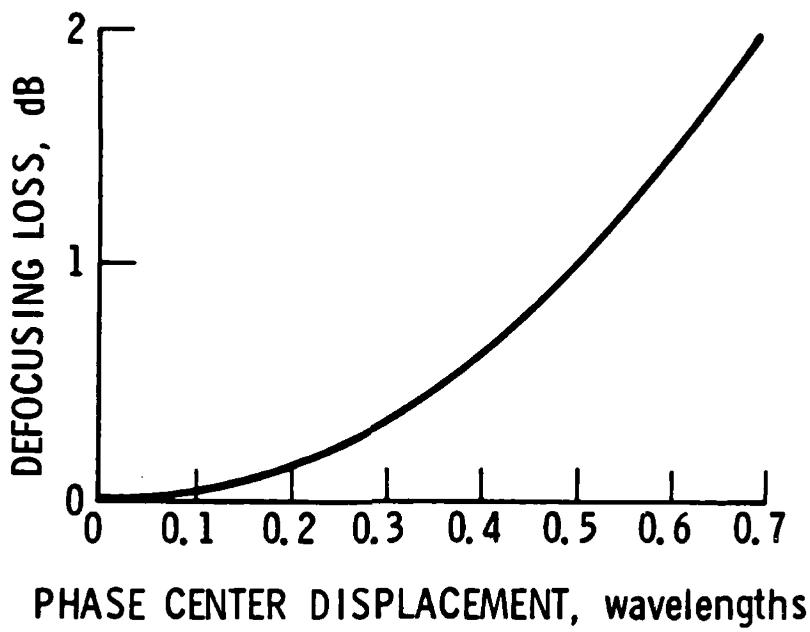

Fig. 3. Defocusing Loss Derived From Fig. 3.

the minimum defocusing and spillover loss when defocusing is not present which supports the previous assertion that a log periodic provides optimum illumination for the reflector.

The loss components considered thus far include only the defocusing and spillover contributions, and more generally impedance mismatch, ohmic, cross polarization, tolerance and blockage components must be included to obtain the antenna efficiency. The concern to this point has been with the gain performance; however, the defocusing also results in pattern degradation which may be important for some applications. The pattern degradation for the cos θ illumination with an f/D of 0.4 reflector has also been treated in Ref. 3 and is repeated in Fig. 4. As will be shown later, the phase center displacement in wavelengths is generally less than one wavelength so that the patterns of the reflector are reasonably well behaved.

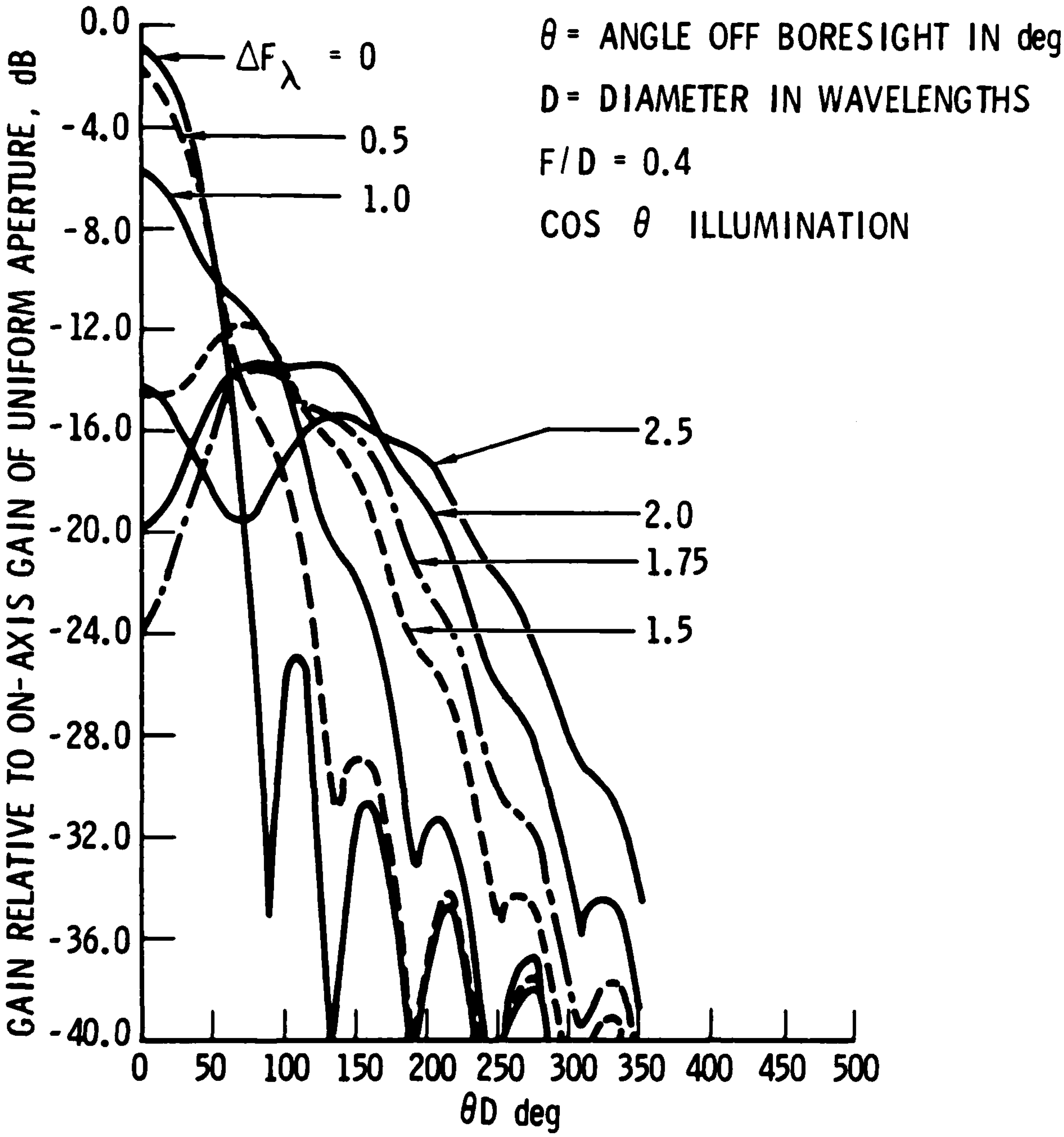

Fig. 4. Pattern Degradation with Defocusing (after Ref. 3)

C. DEFOCUSING LOSS VALUES

The defocusing loss as a function of operating bandwidth will be quantified in this section. The defocusing loss depends on the location of the log periodic relative to the reflector focus and some design latitude exists in this choice. For example, the log periodic feed could be located to provide equal defocusing loss at the frequency extremes of the operating bandwidth. Another choice would be to locate the log periodic feed so that the defocusing loss is zero at the highest frequency; this choice might be made to compensate the increase in ohmic loss with frequency increases as a means to maintain antenna efficiency over the operating bandwidth. The opposite choice, zero defocusing loss at the lowest frequency, does not work for large bandwidths because the phase center displacement in wavelengths increases with increasing bandwidths. Other choices are possible and the analysis presented here can be used to estimate the resulting gain performance; e.g., for a multi-function application, one might want to select zero defocusing loss for the bandwidth segment with the smallest system margin, and estimate the gain performance for other bandwidth segments. The analysis for two cases, equal defocusing loss at the frequency extremes and zero defocusing loss at the highest frequency will be described here.

If the defocusing loss is identical at the frequency extremes, the phase center displacement in wavelengths is also identical at the frequency extremes but oppositely displaced from the reflector focus. In this case,

$$\Delta_l = -\Delta_h \tag{2}$$

where the subscripts "l" and "h" denote the lowest and highest frequency, respectively. The value K in Eq. (1) which results from this condition is given by

$$K = \frac{1}{2\tan\alpha} \frac{c}{f_l + f_h} \tag{3}$$

where c is the speed of light. The phase center displacement in wavelengths as a function of frequency can be written as

$$\Delta = \frac{1}{4\tan\alpha}\left(1 - \frac{2f}{f_l + f_h}\right) \tag{4}$$

and the variation over the frequency range can be determined.

At the center frequency, $\frac{f_1 + f_h}{2}$, the phase center displacement is zero, and the active region of the log periodic is located at the reflector focus. At the frequency extremes, the phase center displacement has its maximum value given by

$$\Delta_{max} = \frac{1}{4\tan\alpha} \frac{f_h - f_1}{f_h + f_1} \tag{5}$$

For many applications, the bandwidth can be conveniently defined as

$$BW = f_h/f_1 \tag{6}$$

and with this definition, the maximum phase center displacement becomes

$$\Delta_{max} = \frac{1}{4\tan\alpha} \frac{BW - 1}{BW + 1} \tag{7}$$

In a similar fashion, the defocusing loss for the case in which the system is focused at the highest frequency can be derived. The parameters for this case will be denoted by "primes" to distinguish the results for the two cases. When the condition for zero defocusing loss at the highest frequency is imposed,

$$K' = \frac{c}{4f_h \tan\alpha} \tag{8}$$

results. The phase center displacement in wavelengths as a function of frequency is given by

$$\Delta' = \frac{1}{4\tan\alpha}(1 - f/f_h) \tag{9}$$

The worst case phase center displacement occurs at the lowest frequency of operation and equals

$$\Delta'_{max} = \frac{1}{4\tan\alpha} \frac{BW - 1}{BW} \tag{10}$$

The worst case defocusing loss and phase center displacement are shown in Fig. 5 for $\alpha = 20^{\circ}$, a typical value for log periodic designs. Both focusing conditions are included in this figure. Initially, it may seem surprising that the defocusing loss asymptotically converges as the bandwidth increases. However, if the projected apex of the log periodic is placed at the focus of the reflector, the phase center displacement in wavelengths equals

$$\Delta'' = \frac{1}{4\tan\alpha} \tag{11}$$

and is independent of frequency because K = 0 in eq. 1; the defocusing loss in this case equals 1.9 dB for $\alpha = 20^{\circ}$. This same value is asymptotically approached for the two focusing conditions used as examples as the bandwidth increases.

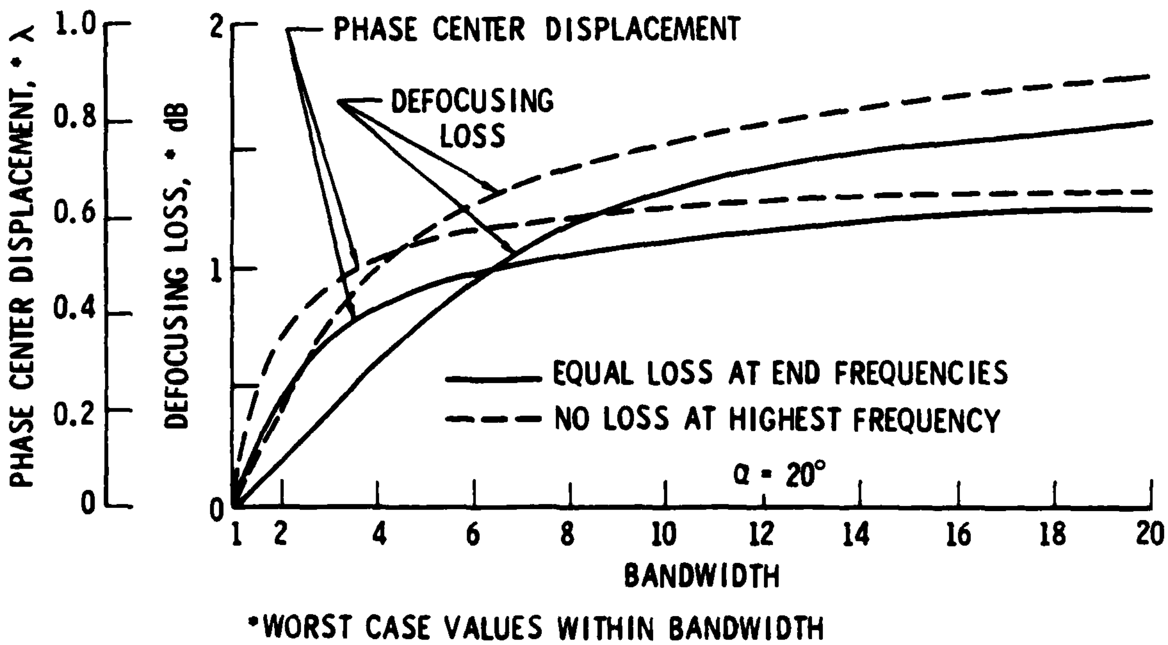

Fig. 5. Defocusing Loss and Phase Center Displacement vs Bandwidth

III. EXAMPLE APPLICATION

The analysis previously developed will be applied in a comparison with measured data. The results of the analysis were used to derive worst case values of the defocusing loss, and the example will also provide the opportunity to examine the variations of defocusing loss over the operating bandwidth.

One vendor who offers a log periodic-fed reflector in their product line is Watkins-Johnson. Gain data for one of their models, AR180-AS, are presented in their catalog (Ref. 4). This particular antenna uses a 3 ft diameter reflector and is fed with a linearly polarized log periodic antenna which covers the range of 1 to 12.4 GHz.

The defocusing loss for this frequency range was calculated under the assumption that the log periodic feed was positioned to result in equal defocusing loss at the extreme frequencies. The resulting phase center displacement and defocusing loss is shown in Fig. 6. The defocusing loss is less than 1 dB over the 2 to 11.5 GHz frequency range.

These defocusing loss values were compared to the measured gain performance published in the Watkins-Johnson catalog. The antenna efficiency at the mid-band frequency, 6.7 GHz, where the defocusing loss is zero, was calculated from the gain data and resulted in a value of 48%. The antenna gain for other frequencies was calculated under the assumption that the overall antenna efficiency was 48% reduced by the defocusing loss as a function of frequency. The resulting antenna gain values compared with the gain data published in the Watkins-Johnson catalog is shown in Fig. 7. The measured gain values correspond well with the results calculated from the defocusing loss analysis. The difference between measured and calculated gain values at the higher frequencies might be caused by an increase in the ohmic loss which is not included within these computations.

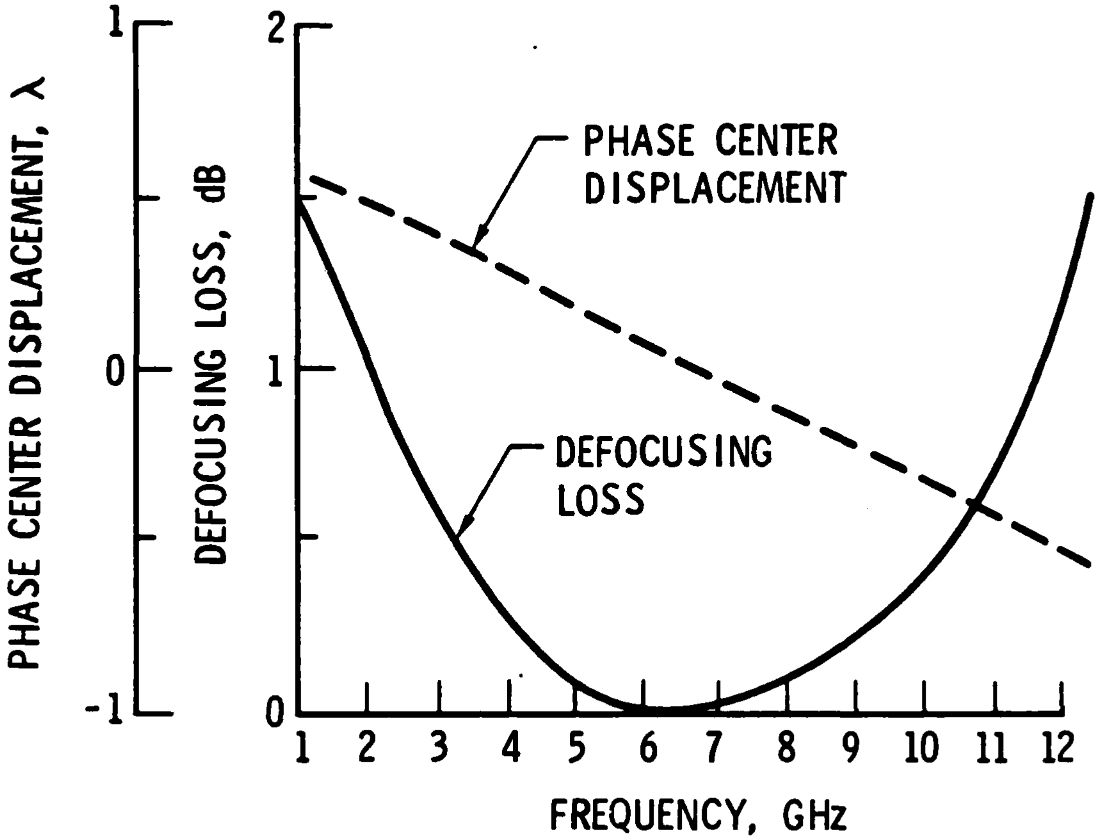

Fig. 6. Phase Center Displacement and Defocusing Loss Values for AR180-AS

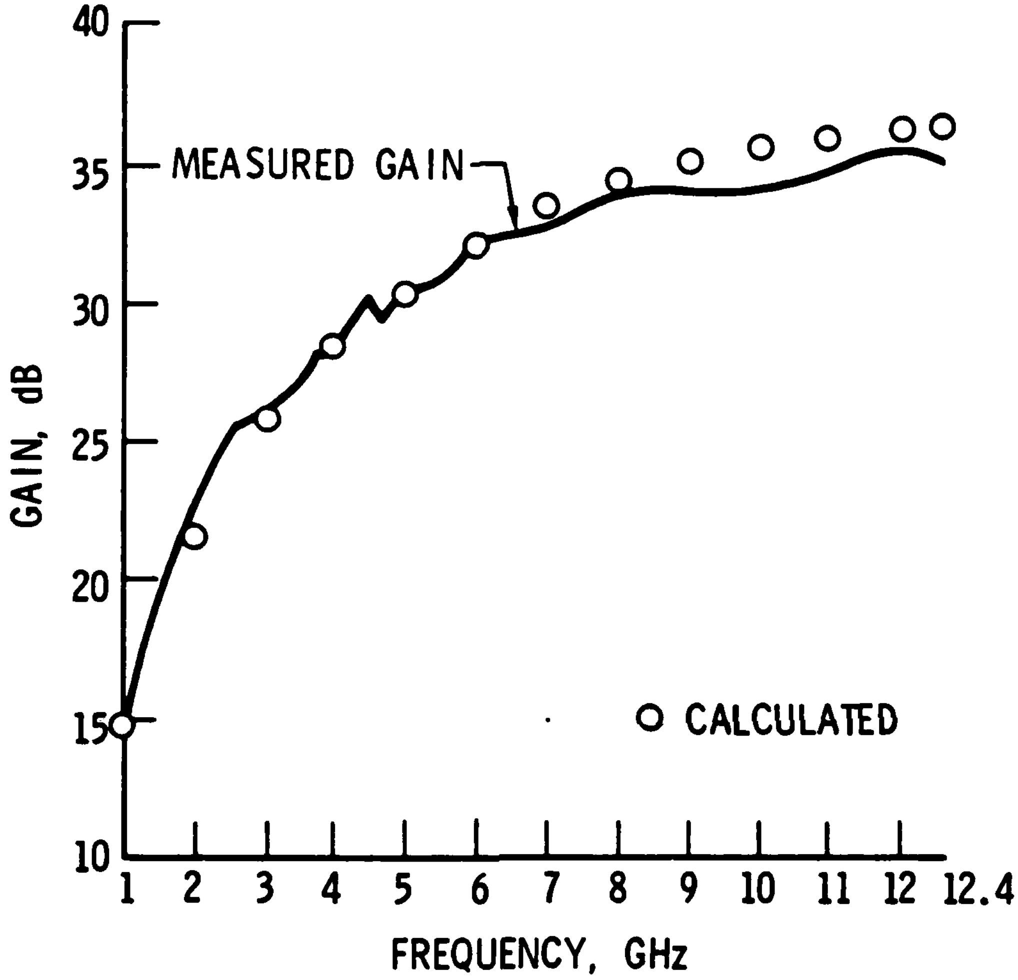

Fig. 7 Measured and Calculated Gain Values for AR180-AS Antenna (Measured data from Ref. 4)

IV. CONCLUSIONS

An analysis has been developed to calculate the defocusing loss which results when a log periodic antenna is used as a feed for a reflector. Some design latitude exists in locating the log periodic relative to the reflector focus. The examples cited illustrate the worst case defocusing loss approached 1.9 dB only for extremely large bandwidths; for 10:1 bandwidths, the worst case defocusing loss is less than 1.3 dB for the case with equal defocusing loss at the frequency extremes, and less than 1.5 dB for the case with zero defocusing loss at the highest frequency. This analysis was compared with published gain data and agreed well with those results. The data covered 1 to 12.4 GHz and the defocusing loss was less than 1 dB over the 2 to 11.5 GHz range. The displacement in wavelengths between the phase center and the reflector focus is relatively small for the cases examined here so that a moderate pattern degradation with defocusing can be anticipated.

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